Cooperative Microsystems

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Report Documentation Page

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MTO Symposium
2-5 March 2009 – San Jose, California

"Cooperative Microsystems"

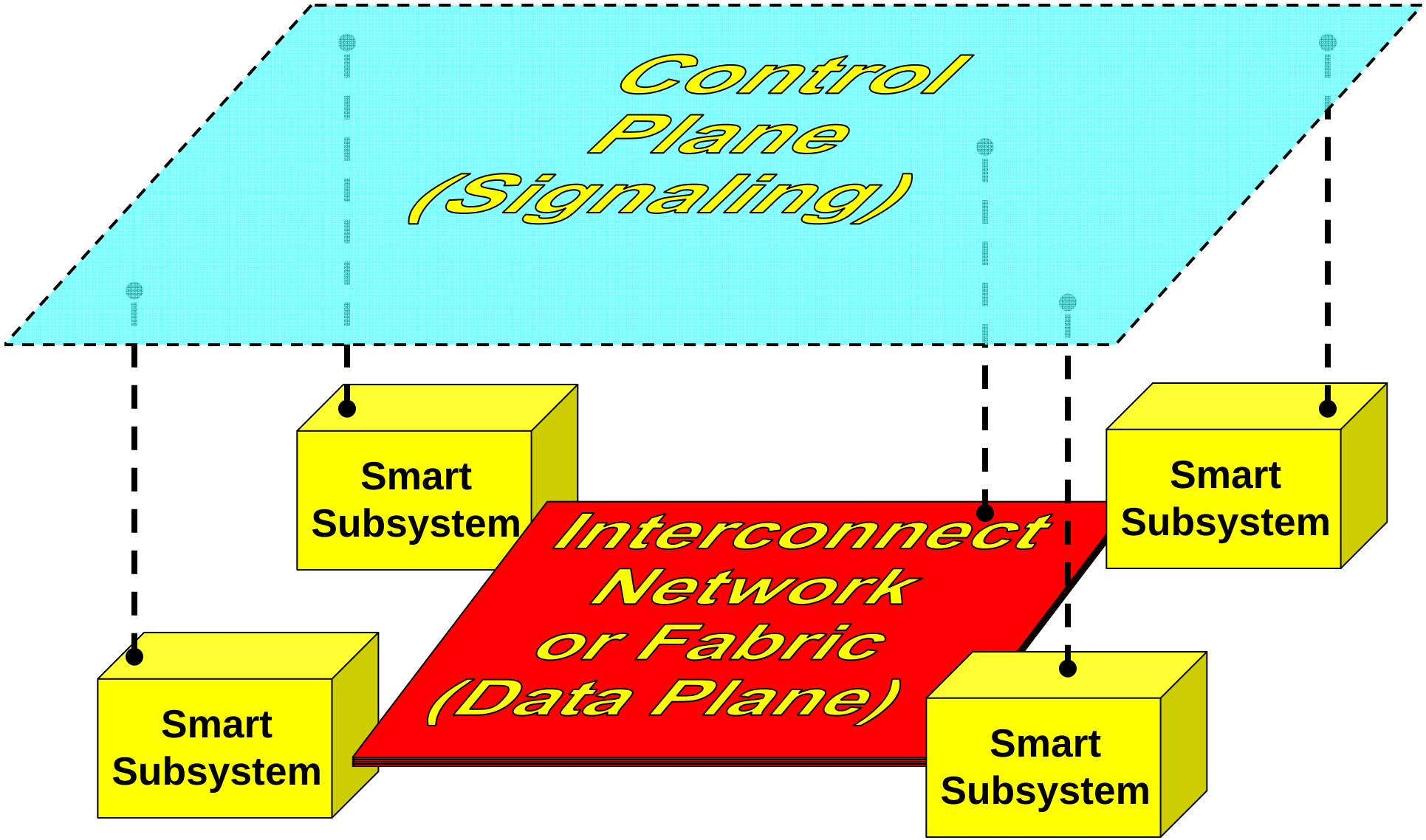
Adel A. M. Saleh

DARPA / MTO

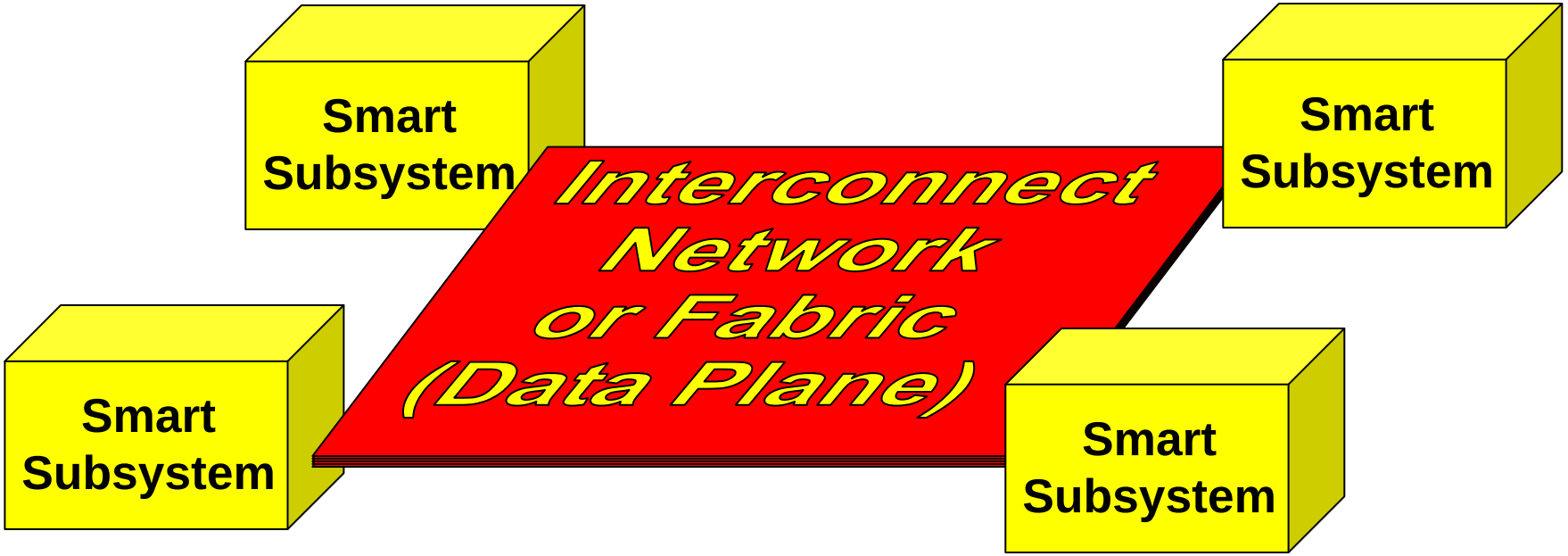
4 March 2009

MICROSYSTEMS TECHNOLOGY OFFICE

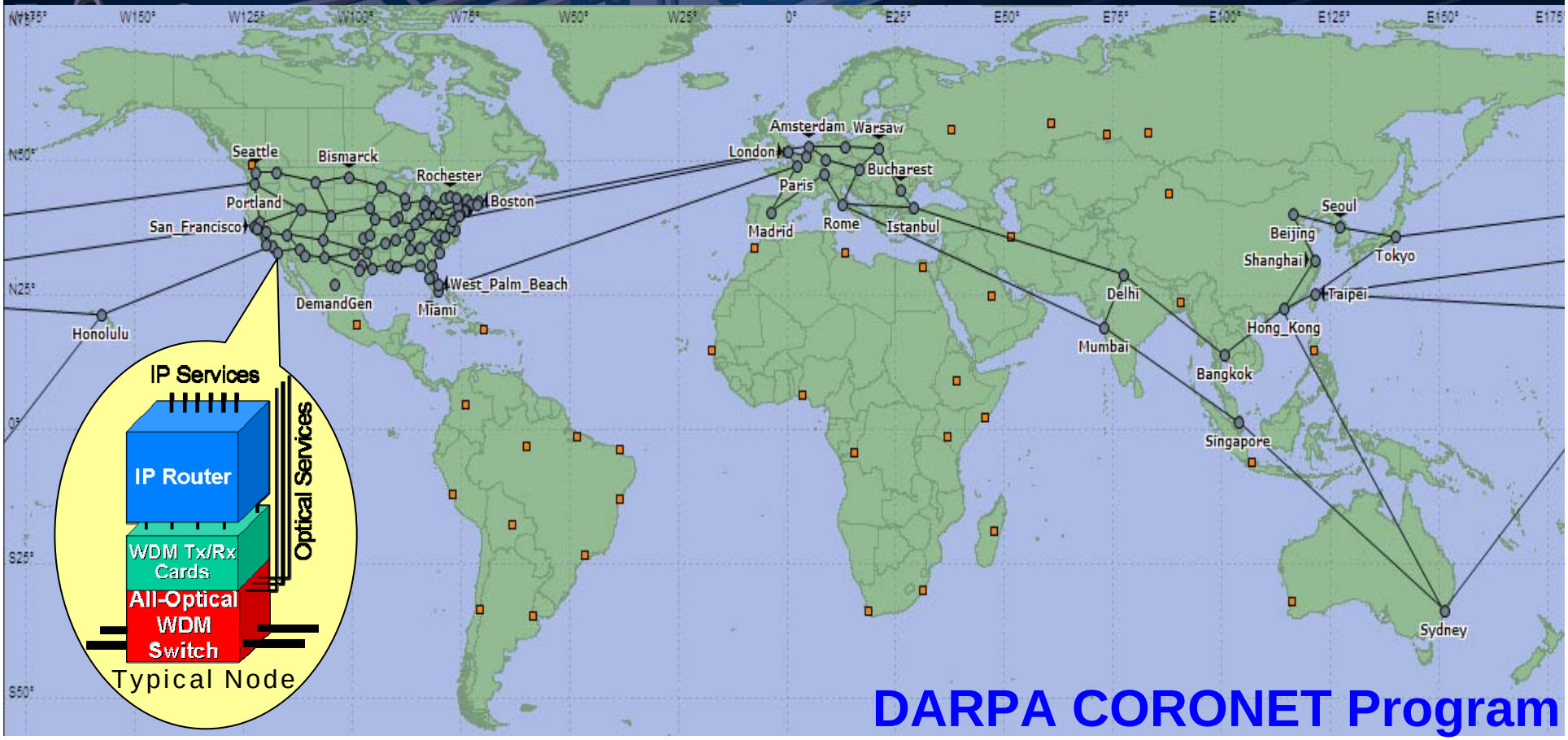
Definition of a Cooperative System



Definition of a Cooperative System



A Cooperative Mega-System
(Global-Scale IP/Optical Network)



DARPA CORONET Program

The Network Nodes Cooperate to Accomplish:

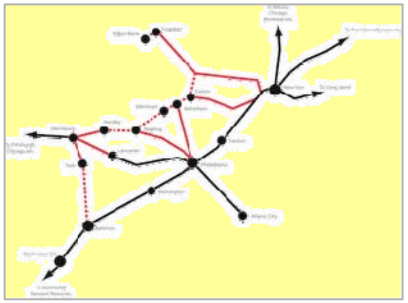
- **Fast, automatic end-to-end provisioning of IP and Optical Services**
- **Fast, automatic recovery from multiple network failures (self healing)**
- **Secure, low blocking, low latency, high efficiency, and huge capacity**

Let Us Shrink the Network by Factors of 10
Each Case is a Cooperative System of Its Own

~5,000 km

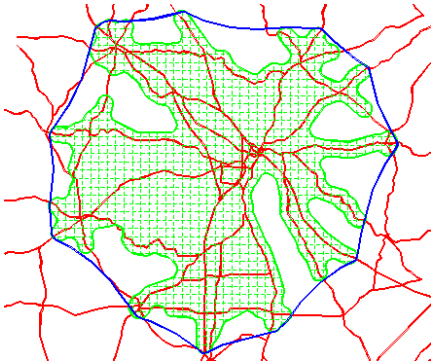
Wide-Area Network (WAN)

~500 km



Regional Network

~50 km



Greater Metropolitan-Area Network (MAN)

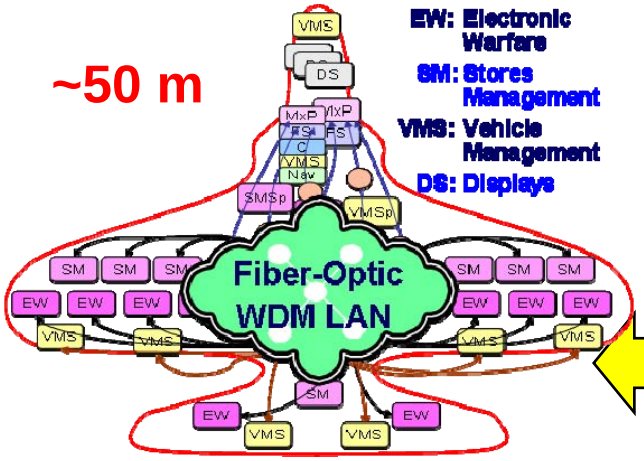
~5 km

Metropolitan-Area Network (MAN)

~500 m

Campus-Scale Local-Area Network (LAN)

~50 m



WDM Local-Area Network (LAN) for Avionic Platforms

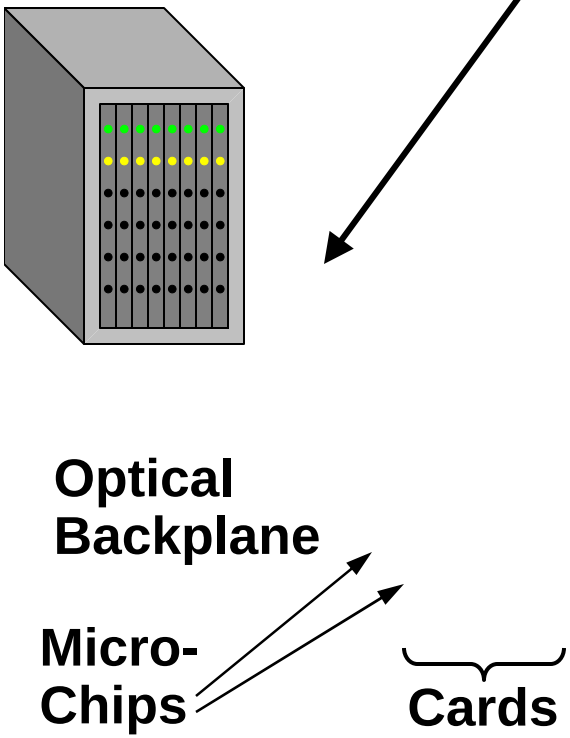
DARPA NEW-HIP Program

Outline of the Rest of the Talk

- A Vision for the Next-Generation, High-Performance Cooperative Microsystems Consisting of Chips, Cards, Shelves and Racks
- Chip-to-Chip Optical Interconnects
  - ***Current and Future Vision***
- On-Chip Cooperative Microsystems
  - ***We will hear two talks on this***
- Summary of the Vision
- Quantum-Scale Cooperative Microsystems
  - ***We will hear two talks on this***
- Biological Cooperative Microsystems
  - ***We will hear one talk on this***

A Vision for the Next-Generation, High-Performance Cooperative Microsystems

The Heart of the Vision is Configurable, Optical, WDM-Based Interconnects to Realize a Plug-and-Play, Multi-Terabit Bus



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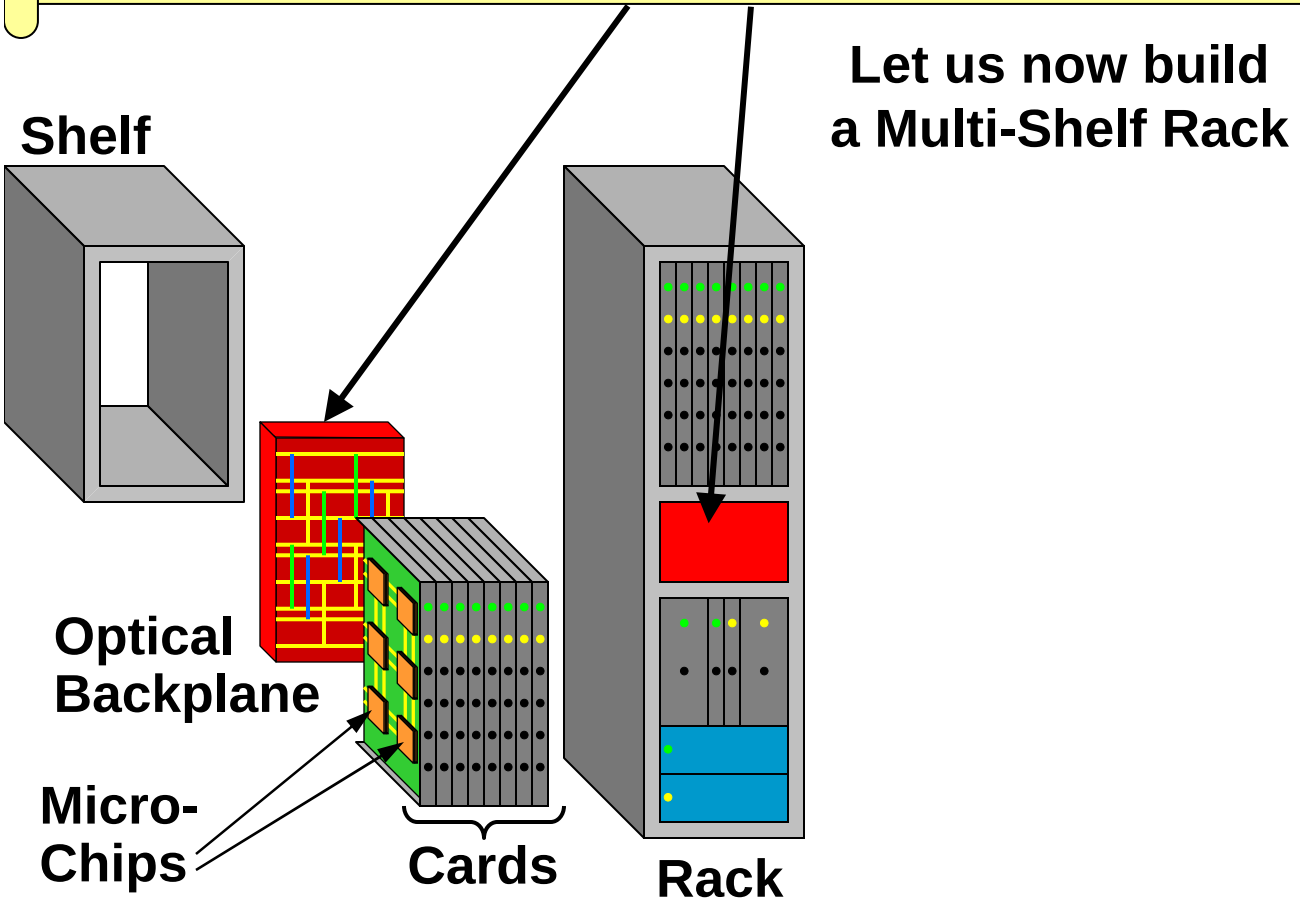

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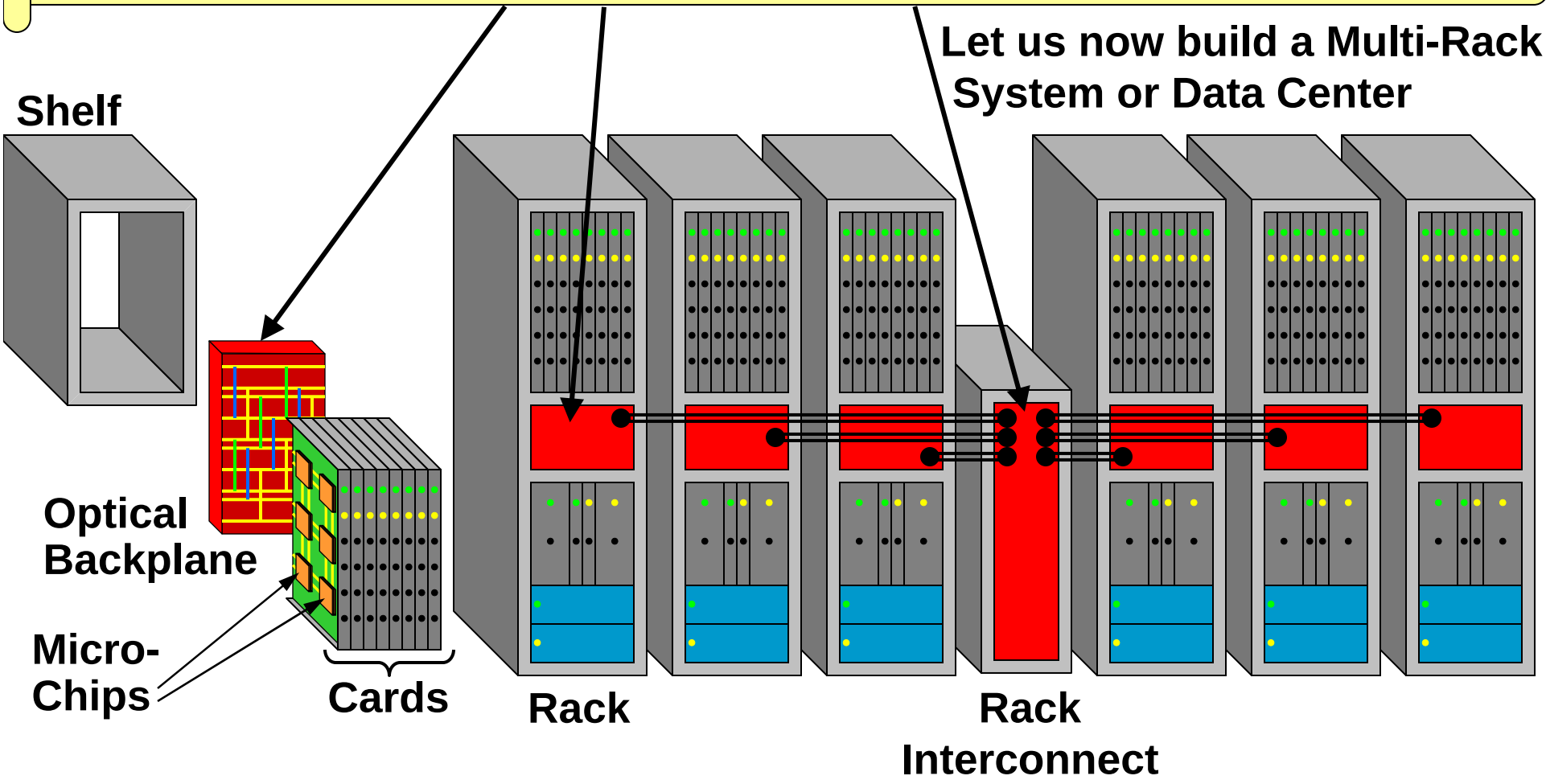
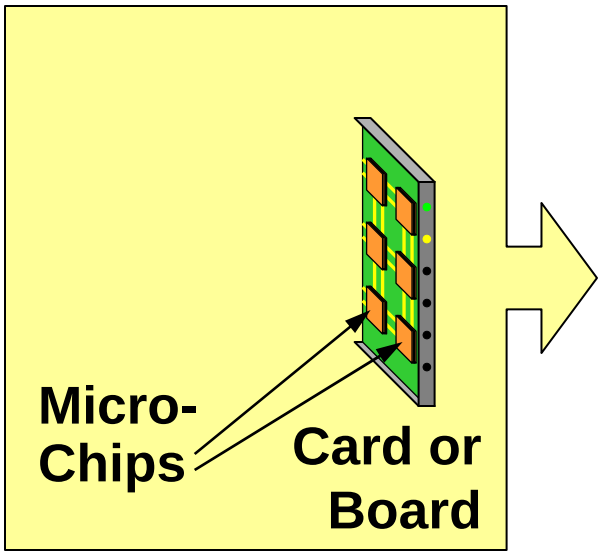
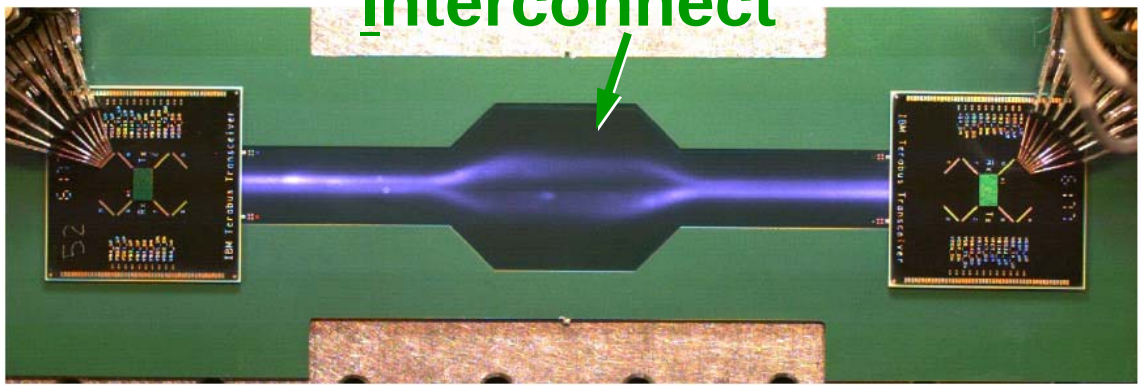


Pushing the Vision Down to the Board and Chip Levels



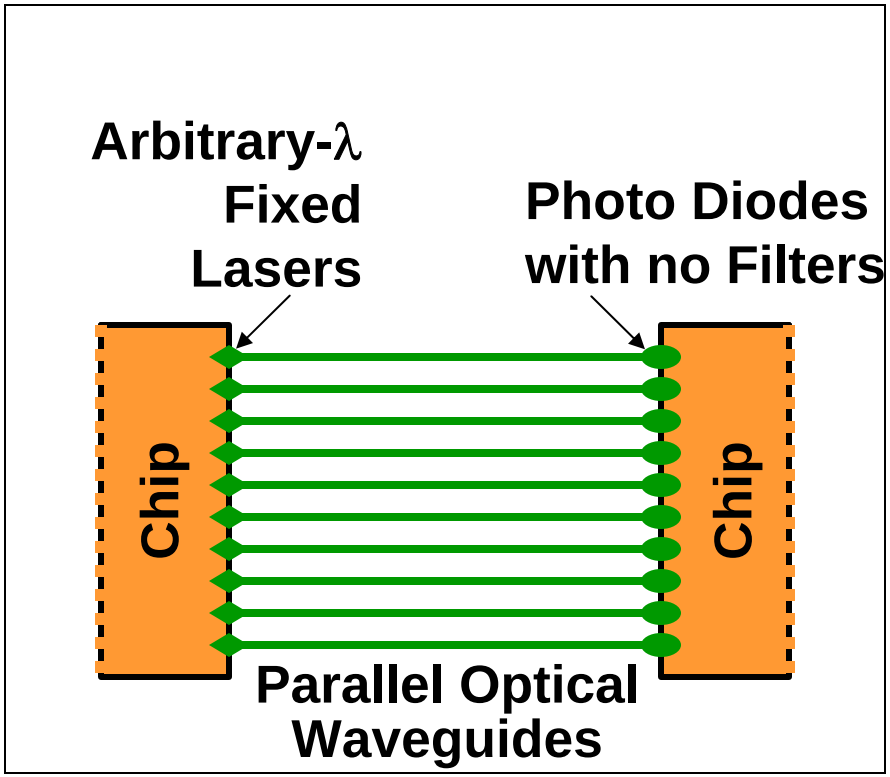
Chip-to-Chip Optical Interconnect



The DARPA C2OI Program

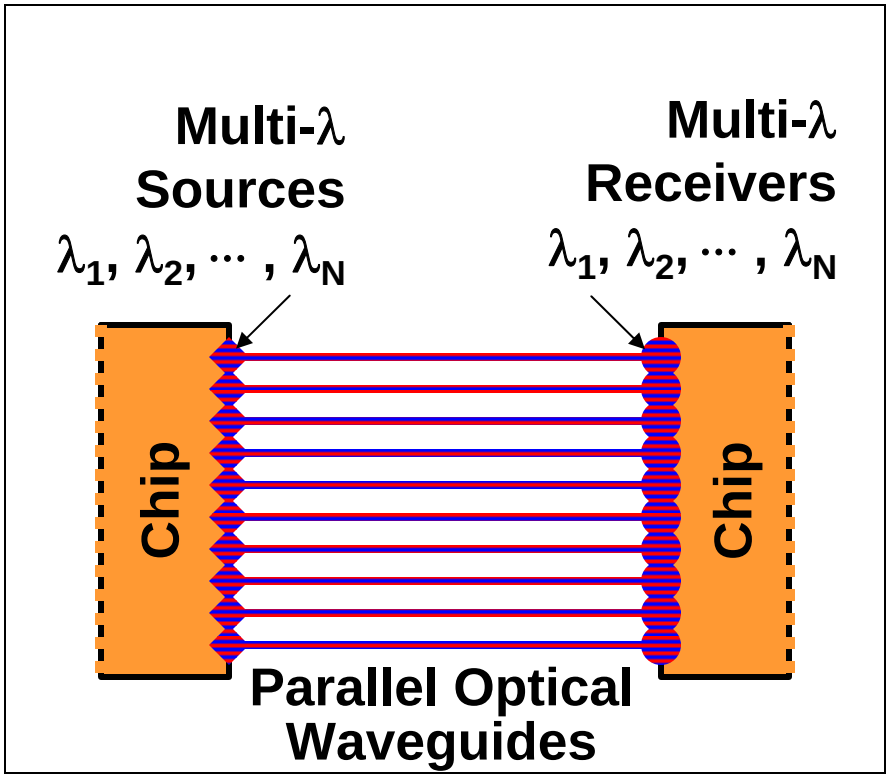
- Board-level and off-board, chip-to-chip optical communication
- Utilizing an array of VCSEL transmitters, parallel waveguides, and photo-diode receivers
- Enables higher bandwidth (>>1 Tbps) and lower power (5 pJ/bit) communication as compared to electronic alternatives.
- Do we need to add **WDM** and **Configurability** to this Vision ?

Why/How to Add WDM and Configurability ?



Static, Parallel Optical Interconnect

** Reference architecture*

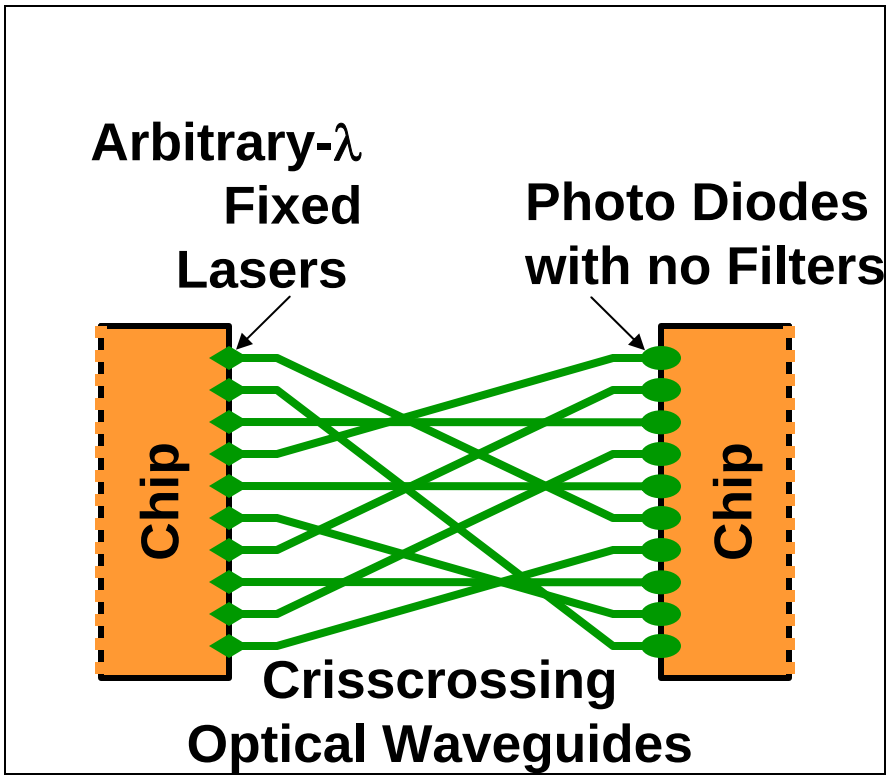


Use WDM <u>to Increase Capacity</u> ?

** Multi-λ transmitters and receiver are large and power hungry*

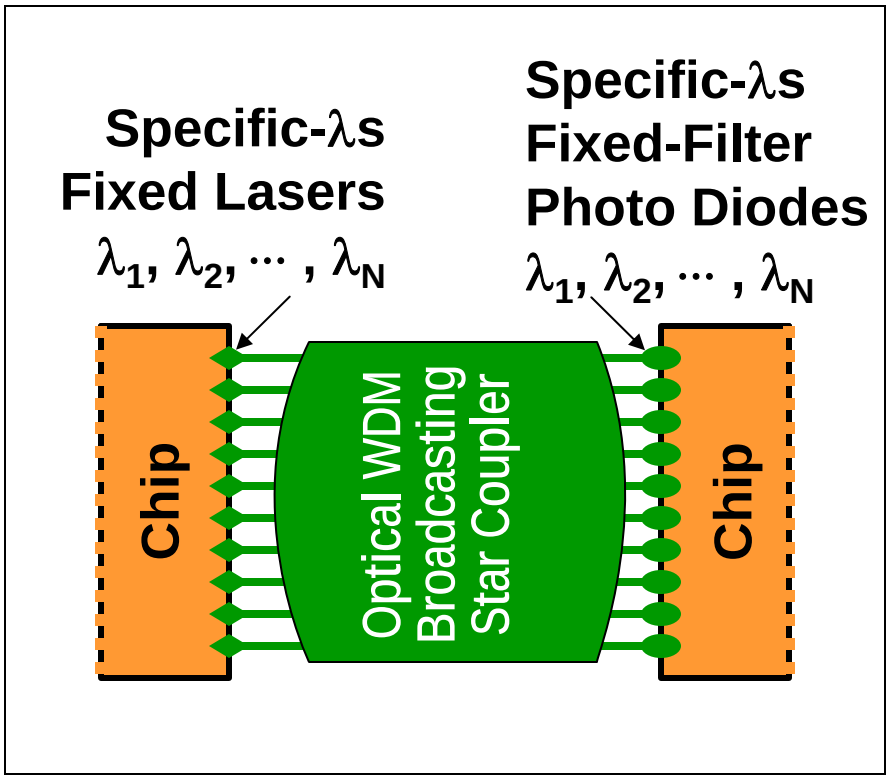
**** I do not believe that this is why one would want to do WDM***

Why/How to Add WDM and Configurability ?



Crisscrossing Optical Interconnect

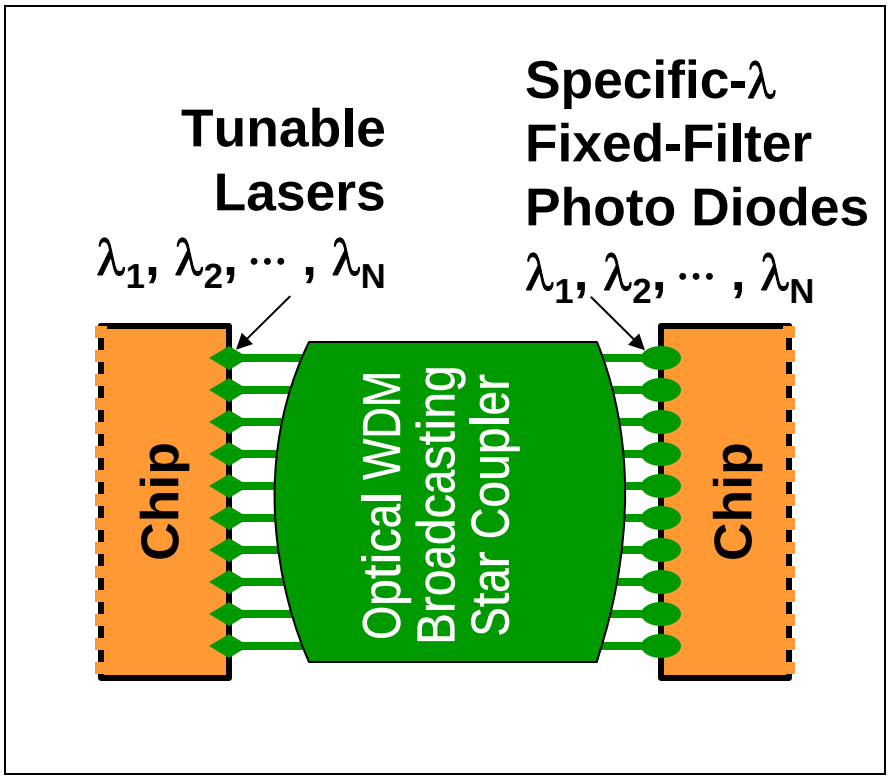
* *Hard to fabricate crossing waveguides with low loss and low cross-talk*
* *Once made, interconnection is static*
* *Not an elegant solution!*



Crisscrossing Optical Interconnect

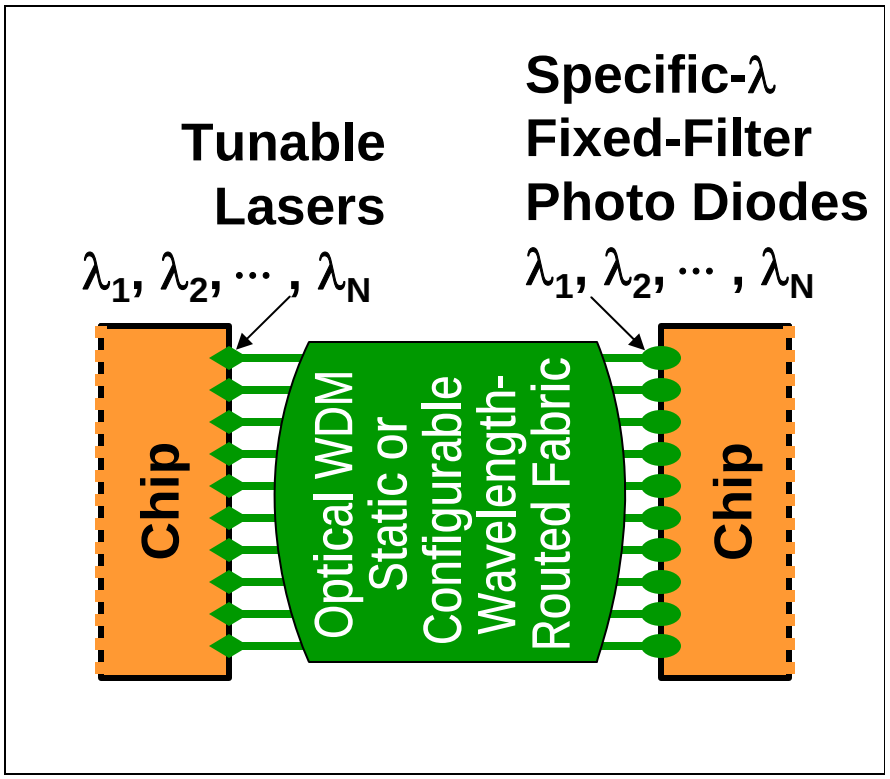
* *More elegant solution*
* *But, we need specific-λs, fixed lasers and filters for this vision*
* *Nominal loss = 1/N*
* *WDM in the fabric, not at the ends*

Why/How to Add WDM and Configurability ?



Configurable Optical Interconnect

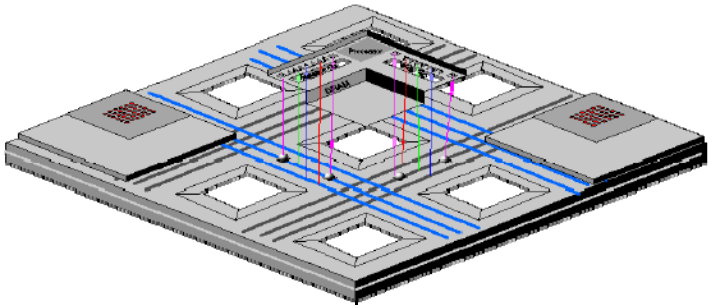
* *We need tunable lasers and specific-λs fixed filters for this vision*
* *Nominal loss = 1/N*
* *WDM in the fabric not at the ends*



Configurable Optical Interconnect

* *Same end device requirements*
* *The fabric can be a static AWG or a tunable cross-bar switch*
* *No nominal 1/N loss*
* *WDM in the fabric not at the ends*

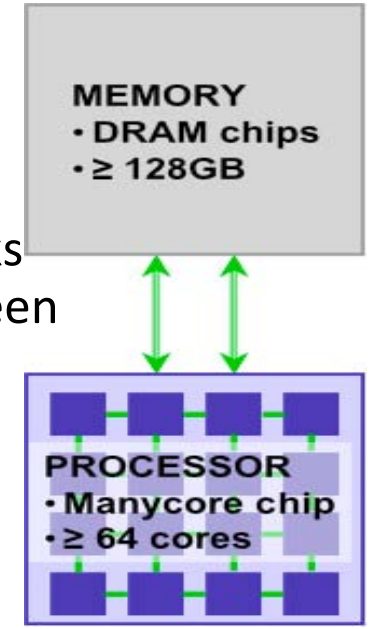
Moving the Vision On-Chip !



The DARPA UNIC Program: Ultraperformance Nanophotonic Intrachip Communications

SUN Microsystems: Macrochip design providing 10 TB/s bisection bandwidth for 64 cores providing 10 TFLOPS

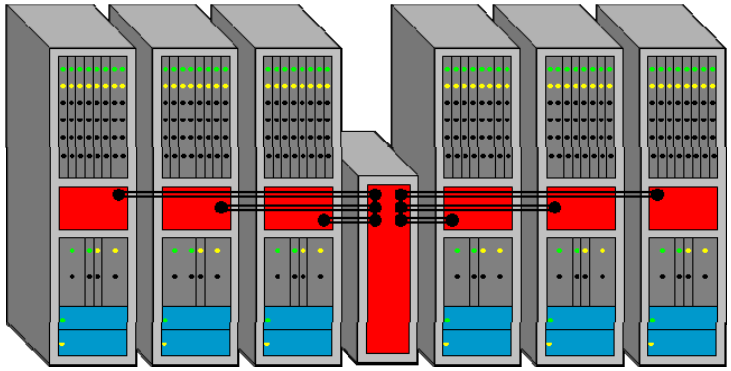
MIT Lincoln Lab: Optimization of optical communication networks among cores, and between cores and memory



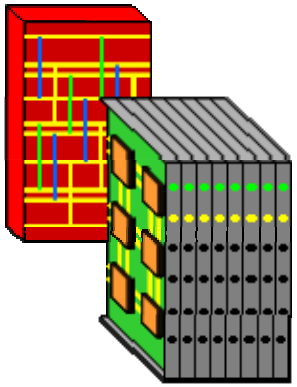
Two Talks:

- Ashok Krishnamoorthy (SUN) **– Intrachip Photonic Communications Networks with Seamless Off-chip Communications: Vision for the Future**
- Jeremy Kepner (MIT/LL) **– Photonically-enabled Optimized Embedded Microprocessors, Shared Memory Optimizing Multicore Cooperation**

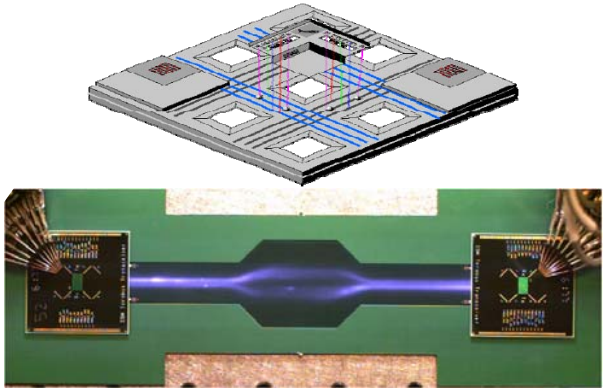
Cooperative Systems of Various Orders of Magnitudes Benefiting from WDM Optical Networking



Intra- / Inter-Rack



Inter-Cards or Boards



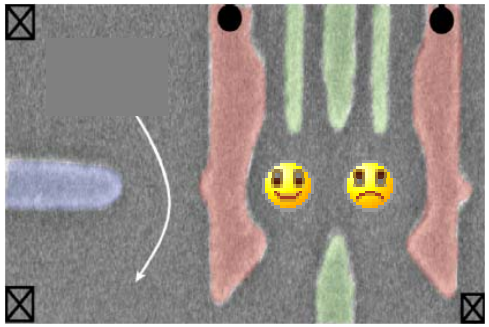
Intra- / Inter-Chip

- Of course, the very same devices and components do not work at all scales of the vision
- But the same basic ideas and architectures promise higher performance (capacity and flexibility) at a reduced cost, size and power for all scales of the vision
- Much more work is needed at all scales to realize this vision of multi-terabit-per-second cooperative microsystems

Cooperative Microsystems at a Quantum Scale

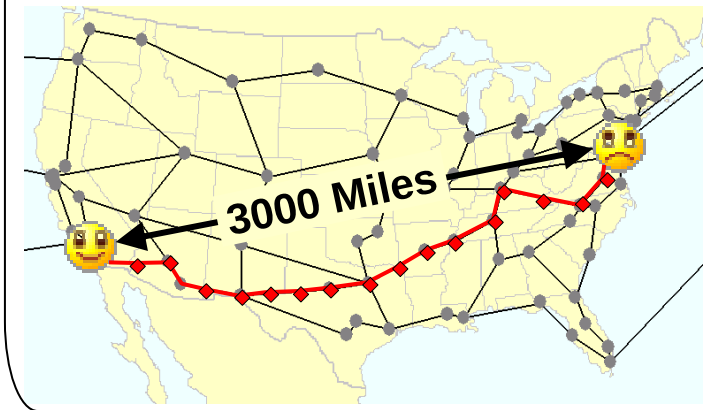
Here, the **subsystems are quantum states**, e.g., electron spin states, photon polarization states, atomic states, etc., and the **interconnect is quantum entanglement**, "*the spooky action at a distance*"

Entanglement of electron spins in quantum dots defined by gate voltages



Today, scientists have succeeded in realizing secure Quantum Key Distribution (QKD) over ~100-km free-space or fiber-optic links using the **BB84 Protocol** conceived by **Bennett** and **Brassard** in 1984

The holy grail of QKD is to extend the distance to continental scale, using entanglement-based "**quantum repeaters**"



Two Talks:

- Charles Marcus (Harvard) – **Cooperative Quantum Microsystems**
- Charles Bennett (IBM) – **The Promise of Quantum Key Distribution**

Part of the vision in this sub-session is related to the DARPA QuEST Program

And finally for something completely different !

A Talk by:

- Joe Pancrazio (NIH) **– on "Prosthetics, Interconnects, Neuro-Photonics"**

Note that *Interconnects* is a common theme, other than that, it is a completely different story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